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Air and surface soil samples – two different pairs of shoes? Comparing the pollen spectrum on different days of the pollen season

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Abstract

The pollen spectra of air and surface soil samples from a rooftop (at 14 m) and from ground level (at 1.6 m) in the suburbs of Vienna (Austria) were compared. Two soil samples and two air samples were taken on four different days to account for possible differences: in winter when no pollination occurred (reference day), in spring during the main flowering of *Betula* (birch day), in spring/summer during the main flowering of Poaceae (grass day), and in autumn during the main flowering of *Ambrosia* (ragweed day). Thirty-five different pollen types were used to describe the pollen spectra. Frequencies of certain pollen types reflect a seasonal impact on both the surface soil and air samples and show a similarity between air and soil samples on most of the days. However, the seasonal impact is higher in the air samples and shows a high consistency for ground and rooftop level. Kendall's tau correlation coefficients further substantiate the similarities of the samples especially for the pollen season days. Exceptions include the winter day when pollination was low and the air samples recorded nearly no pollen at all, and the ragweed day when *Ambrosia* pollen was abundant in three of four samples but not in the ground surface soil sample. Thus, (1) air and surface pollen samples record similar signals during the pollen season but not during the ragweed and winter season and (2) air and surface pollen samples show the impact of local vegetation also in pollen traps located at different heights.

Keywords: pollen spectrum, pollen concentrations, Hirst-type volumetric traps, air samples, surface soil samples, outdoor air

The evaluation of air samples is the basis of aerobiology and pollen information services. Air samples are acquired in Europe mainly by means of the Hirst-type pollen and spore traps (Hirst 1952), which suck in air that is spread on a plastic/silicon tape on a rotating drum. The advantage of these devices is an uninterrupted sampling period of seven days and the volumetric operation reflecting more accurately the changes of pollen concentrations in comparison to a Rotorod sampler (Frenz 1999), which works gravimetrically. Hirst-type pollen traps suck in air through a 2 mm × 14 mm slit at a rate of 10 L/min, corresponding to the amount of air taken in by human lungs. However, it is essential to know the real air flow of the pollen trap as a significant systematic error may occur due to the

used rotameter and the trap (Oteros et al. 2017). Quality control is a major topic also for the evaluation of air samples. Thus, minimum requirements were formulated and supported by the scientific community (Galán et al. 2014), societies (EAS, European Aerobiology Society; <http://www.eas-aerobiology.eu/ean/>) and databases (EAN, European Aeroallergen Network; <https://www.ean-net.org/en/the-ean-database/what-is-ean.html>). Those include, for example, the preparation of air samples. The tape used has to be sticky (using Vaseline or silicone surfaces). The clockwork ensures a movement of the drum at a rate of 2 mm/h (48 mm = 24 h of sampling). The sticky tape is divided into certain temporal periods (days), applied to slides and stained with a dye for improved visibility of organic

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particles such as pollen. Evaluation is performed at 40 × magnification. Only trained personnel evaluate the data and applies a correction factor that takes into account the field of view, the lines counted, and the microscope attributes to result into daily mean pollen concentrations that are comparable over countries, analysts, and years. Detailed information on the history of pollen measurements, problems with pollen measurements and personal pollen samplers is reviewed in Berger et al. (2014). Furthermore, automatic pollen counting is increasingly used and has been tested during recent years. Devices such as the PLAIR PA-300 (Crouzy et al. 2016) are tested in Switzerland or the BAA 500 (Oteros et al. 2015) in Bavaria (Germany). Hitherto no national pollen monitoring network in Europe relies solely on automated pollen counts due to the still existing flaws such as incorrectly identified pollen (lower precision rates than in the traditional method), limited pollen types that are identified, incomparability to existing datasets, necessity of databases to be built, and inflexibility of the machines (e.g. difficulties to identify clumped or fragmented pollen). Those problems are addressed in Bastl et al. (2017a), where more information on other pollen detection systems can be found. Air samples (aerobiological samples) and their results are crucial for pollen forecasting, pollen distribution models, medication and treatment of pollen allergies. Pollen allergies are a global health concern that causes direct and indirect costs in the health sector and affects the quality of life (WAO 2013). Pollen information and forecasts are among the key factors for allergen avoidance (Kiotseridis et al. 2013). Therefore, caution has to be taken when working with pollen forecasts and air samples, since they have a considerable impact on pollen allergy sufferers and their daily routines such as medication intake (Bastl et al. 2017a).

Surface soil samples and their pollen content are of high interest for a range of disciplines such as palaeontology (palaeobotany, palaeoecology), archaeology, ecology and forensic palynology (e.g. Davidson et al. 1999; Mildenhall 2008; Grímsson et al. 2016; Kelso & Miller 2016; Sun et al. 2016). Previous studies discussed processes, which might affect the pollen content of soil samples, among those bioturbation, translocation, differential destruction or anthropogenic disturbance (e.g. Havinga 1974). Furthermore, different hypotheses have been proposed of how pollen assembled in soil: (1) pollen is bound in humic complexes and grains cannot be moved (Dimbleby 1985); (2) pollen grains move individually through the soil void space by downwashing (Kelso 1994); (3) soil fauna incorporates and redistributes pollen in soils (Andersen 1979). Davidson et al. (1999) suggested

that soil fauna is the most important component for incorporation and redistribution of pollen in soils: pollen deposited on the soil surface was consumed, digested and excreted by invertebrates; pollen was strongly associated with larger invertebrate excrement; pollen is moved laterally and vertically by earthworms (if present); no evidence for humic complexes or for downwashing was found; it is unlikely that pollen grains are totally removed by translocation from profiles. Therefore, soil pollen content is a single mixed-age assemblage down to the maximum depth of relevant invertebrate activity (Davidson et al. 1999). Surface soil pollen assemblages proved useful in forensic palynology and show the local impact of the assemblage (e.g. Brown et al. 2002; Riding et al. 2007).

To date, it remains unknown if, and to what extent, the pollen spectra in air and surface soil samples correspond when considering more than one pollen type and for samples from different heights regarding the pollen trap. Our working hypothesis was that air and surface soil samples would contain similar pollen and that there is a seasonal pattern in the pollen content of both types of samples. This is the first comparative study on pollen content at ground level and rooftop level in air and surface soil samples. The purpose of this study was to assess if and how air and soil samples are comparable or supplement each other.

Material and methods

Surface soil samples as well as outdoor pollen concentrations on rooftop and ground level were collected at four different days during the years 2015/2016 (Figure 1). The data was collected during a study that assessed the indoor pollen spectrum via air and dust samples in order to assess the relationship of outdoor to indoor pollen samples (Bastl et al. 2017b). The first day was selected as a reference day during winter time when no/little pollen was present in the ambient air (14 December 2015; ‘winter day’). The following samples were taken during the pollen season, meaning not randomly, and during a high burden of three major aeroallergens in the spring during the flowering of birch (4 April 2016; ‘birch day’), in early summer during the flowering of the grass family (30 May 2016; ‘grass day’), and in late autumn during the flowering of ragweed (8 September 2016; ‘ragweed day’). The local vegetation on the grounds of the ZAMG consists of various types of plants of allergenic interest in a radius of about 300 m (Table I), which provide a local source of pollen.

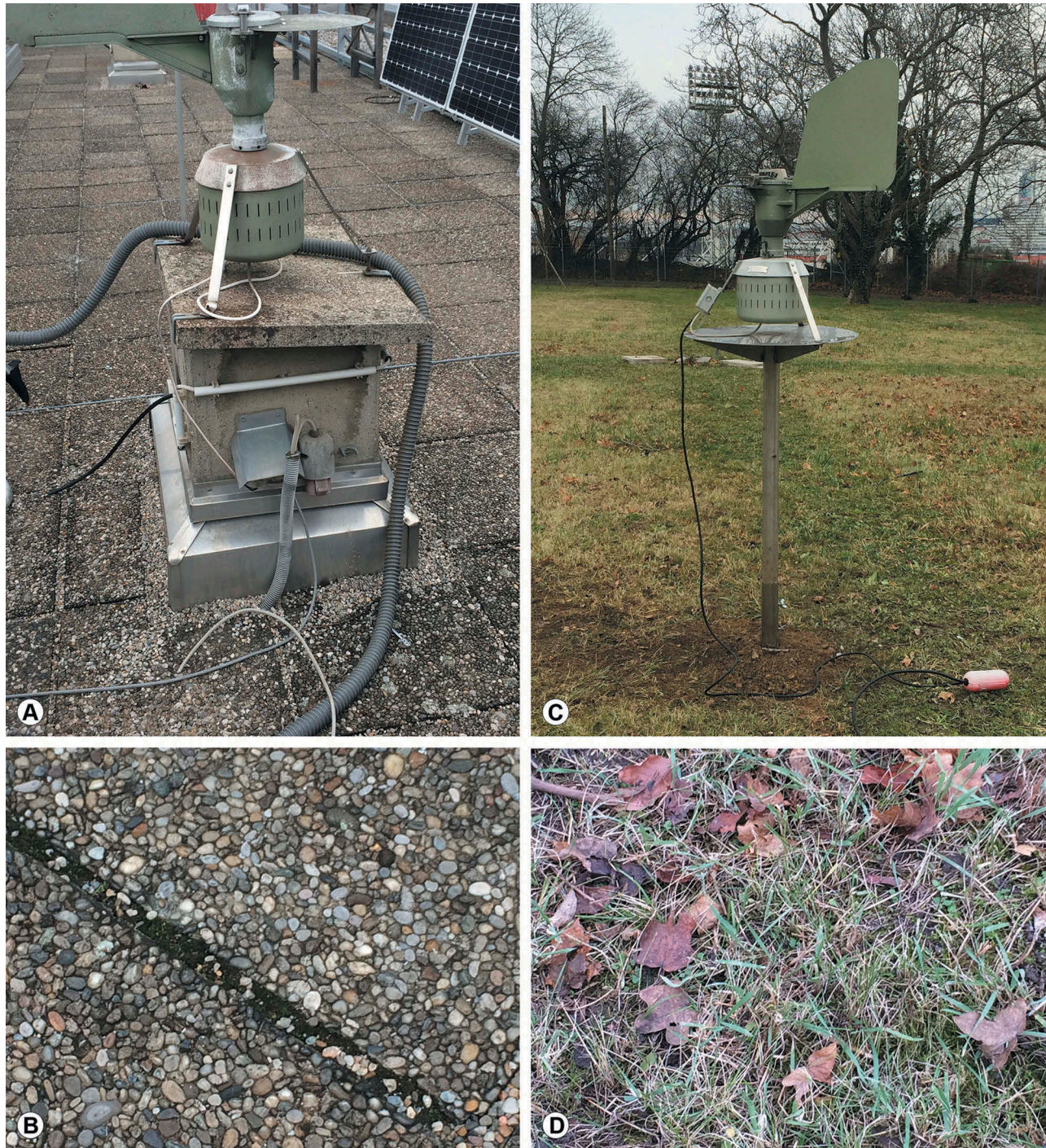


Figure 1. **A, B.** Rooftop of the Karl-Kreil building at the Zentralanstalt für Meteorologie und Geodynamik (ZAMG). **A.** Pollen trap. **B.** Nature of the ground, where surface soil samples were collected. **C, D.** Phenological garden of the ZAMG. **C.** Pollen trap. **D.** Nature of the ground, where surface soil samples were collected.

Palynological evaluation

Palynological analysis was performed on all surface soil and air samples. All taxa were selected based on their frequency and allergological relevance as previously described in Bastl et al.

(2017b). The air samples were evaluated totally (every pollen grain) by the same observer (MB), whereas the soil samples were evaluated until a maximum of 300 pollen grains by the same observer (MW) to avoid intra-observer error for

Table I. Vegetation list of plants of allergenic importance or present with their pollen in the air and soil samples at the area of the ZAMG (maximum radius of 300 m).

Taxa	Present at the area of the ZAMG	Found in the air/soil samples, but not present
<i>Acer</i>	X	
<i>Aesculus</i>	X	
<i>Ailanthus</i>	X	
<i>Alnus</i>		X
Amaranthaceae	X	
<i>Ambrosia</i>		X
Apiaceae	X	
<i>Artemisia</i>	X	
Asteraceae	X	
<i>Betula</i>	X	
Brassicaceae		X
<i>Carpinus</i>	X	
Caryophyllaceae	X	
<i>Castanea</i>		X
<i>Corylus</i>	X	
Cupressaceae	X	
Fabaceae	X	
<i>Fagus</i>	X	
<i>Fraxinus</i>	X	
<i>Juglans</i>	X	
<i>Mercurialis</i>		X
<i>Plantago</i>	X	
<i>Platanus</i>	X	
Poaceae	X	
<i>Populus</i>	X	
<i>Quercus</i>	X	
Ranunculaceae	X	
Rosaceae	X	
<i>Rumex</i>		X
<i>Salix</i>	X	
<i>Sambucus</i>	X	
<i>Tilia</i>	X	
<i>Ulmus</i>	X	
Urticaceae/Can.	X	

air and soil samples. In total, 35 taxa/groups were included and evaluated (Tables II–VI). The following procedures were used to homogenise the dataset of the surface soil and the pollen concentration data: Cannabaceae was included in Urticaceae, *Zea mays* L. and *Secale* were included in Poaceae, taxa of Asteraceae other than *Artemisia* and *Ambrosia* were grouped together and taxa of the group Taxaceae/Cupressaceae were evaluated as a group to which we refer as Cupressaceae. Taxa completely removed from the dataset and not considered during analysis due to their low allergenic relevance in Austria were: Pinaceae (such as *Abies*, *Cedrus*, *Pinus*, *Picea* and *Larix*) and indeterminate pollen. The ‘INR’ group included identified but not relevant pollen due to their low frequency such as *Broussonetia*, *Ginkgo*, *Hedera*, Oleaceae (other than *Fraxinus*), *Ostrya*, *Phacelia*, *Parthenocissus*, *Philadelphus*,

Table II. Percentage per taxon evaluated (35 pollen taxa/groups in alphabetical order) assessed on the winter day (14 December 2015) from the four compared samples: outdoor rooftop pollen concentrations, soil sample from the rooftop, outdoor ground level pollen concentrations and soil sample from the ground.

Evaluated taxa 14 December 2015	Rooftop sampler (%)	Soil sample rooftop (%)	Ground sampler (%)	Soil sample ground (%)
<i>Acer</i>	—	—	—	1.7
<i>Aesculus</i>	—	0.3	—	—
<i>Ailanthus</i>	—	—	—	0.8
<i>Alnus</i>	—	2.1	—	0.6
Amaranthaceae	—	6.0	—	3.0
<i>Ambrosia</i>	—	9.9	—	6.1
Apiaceae	—	—	—	0.1
<i>Artemisia</i>	—	—	—	0.3
Asteraceae	—	1.2	—	4.1
<i>Betula</i>	—	8.7	—	4.7
Brassicaceae	—	1.8	—	1.3
<i>Carpinus</i>	—	0.3	—	—
Caryophyllaceae	—	—	—	—
<i>Castanea</i>	—	0.3	—	0.5
<i>Corylus</i>	—	3.3	—	0.2
Cupressaceae	—	6.9	—	0.9
Fabaceae	—	0.3	—	—
<i>Fagus</i>	—	0.6	—	0.3
<i>Fraxinus</i>	—	3.3	—	1.9
<i>Juglans</i>	—	0.6	—	1.1
<i>Mercurialis</i>	—	2.1	—	—
<i>Plantago</i>	—	2.1	—	8.2
<i>Platanus</i>	—	—	—	—
Poaceae	—	15.3	—	47.2
<i>Populus</i>	—	—	—	0.2
<i>Quercus</i>	—	1.2	—	3.6
Ranunculaceae	—	1.5	—	1.1
Rosaceae	—	0.6	—	0.9
<i>Rumex</i>	—	—	—	0.5
<i>Salix</i>	—	—	—	0.3
<i>Sambucus</i>	—	—	—	0.5
<i>Tilia</i>	—	24.4	—	5.4
<i>Ulmus</i>	—	—	—	0.2
Urticaceae/Can.	—	0.6	100	—
INR	—	6.3	—	4.4

Polygonaceae, *Robinia*, Rubiaceae, *Tamarix*, *Vitis* and *Viburnum* (same method as in Bastl et al. 2017b).

Sampling and preparation

Two pollen and spore traps of the Hirst design (Hirst 1952; Burkard Manufacturing Co. Ltd) were used in this study to evaluate the daily mean pollen concentrations outdoors on rooftop and on ground level (Figure 1A, C). Both pollen traps are located at the property of the Austrian National Weather Service (Zentralanstalt für Meteorologie und Geodynamik; ZAMG) in Vienna. The rooftop pollen trap is situated on the

Table III. Percentage per taxon evaluated (35 pollen taxa/groups in alphabetical order) assessed on the birch day (4 April 2016) from the four compared samples: outdoor rooftop pollen concentrations, soil sample from the rooftop, outdoor ground level pollen concentrations and soil sample from the ground.

Evaluated taxa 4 April 2016	Rooftop sampler (%)	Soil sample rooftop (%)	Ground sampler (%)	Soil sample ground (%)
<i>Acer</i>	1.9	11.6	0.7	5.5
<i>Aesculus</i>	—	—	—	—
<i>Ailanthus</i>	—	—	—	—
<i>Alnus</i>	0.3	5.7	0.1	12.3
Amaranthaceae	—	—	—	0.2
<i>Ambrosia</i>	—	—	—	—
Apiaceae	—	—	—	—
<i>Artemisia</i>	—	—	—	—
Asteraceae	—	—	—	1.7
<i>Betula</i>	49.7	26.0	48.4	16.5
Brassicaceae	—	—	—	—
<i>Carpinus</i>	12.9	27.3	13.2	25.9
Caryophyllaceae	—	0.3	—	—
<i>Castanea</i>	—	—	—	—
<i>Corylus</i>	0.4	0.5	0.1	3.0
Cupressaceae	10.8	4.9	10.1	7.2
Fabaceae	—	—	—	—
<i>Fagus</i>	—	—	—	0.4
<i>Fraxinus</i>	7.0	5.7	9.4	8.7
<i>Juglans</i>	—	0.3	—	0.2
<i>Mercurialis</i>	—	—	—	—
<i>Plantago</i>	—	—	—	0.4
<i>Platanus</i>	0.1	—	—	—
Poaceae	—	—	—	0.2
<i>Populus</i>	15.7	13.5	16.2	5.1
<i>Quercus</i>	—	—	—	1.2
Ranunculaceae	—	—	—	1.2
Rosaceae	0.1	0.3	0.7	0.2
<i>Rumex</i>	—	—	—	—
<i>Salix</i>	0.9	0.7	0.7	4.2
<i>Sambucus</i>	—	—	—	—
<i>Tilia</i>	—	—	—	—
<i>Ulmus</i>	0.2	0.5	0.2	4.2
Urticaceae/Can.	0.1	—	—	—
INR	0.1	3.0	0.1	1.3

rooftop of the Karl-Kreil building (coordinates: 48.248889, 16.356250) at an elevation of 14 m. The ground level trap is located in the phenological garden of the ZAMG (coordinates: 48.248583, 16.357500) at human height (operating on 1.6 m). Both devices are located in a suburban area without adjacent buildings but gardens and individual buildings nearby, and in a linear distance of approximately 100 m from each other. Vegetation on the grounds of the ZAMG consists of trees, shrubs and herbaceous plants including many of allergenic importance (Table I). Weather was mostly fair on all sample days without major rain showers to assure high pollination on the season days and shall be shortly summarised in the following (Bastl et al. 2017b): The sampling days were chosen based

on forecasts to ensure respectively high birch/grass/ragweed pollen concentrations in addition to a reference day during the winter. No rain occurred during all four sampling periods. The weather was mild on 14 December 2015 with temperatures of about 5 °C (minimum temperature (Tmin) = 3.6 °C, maximum temperature, Tmax = 5.7 °C), but with cloudy conditions and only a few sunny spells. The main wind direction was from the east (with 2.5 m/s wind speed). The weather was sunny on 4 April 2016 with temperatures of 14 to 18 °C (Tmin = 7.4 °C, Tmax = 22 °C). The main wind direction was from the east (with 2m/s wind speed). The weather was dry and partly sunny during the sampling period on 30 May 2016 with temperatures of 22 to 23 °C (Tmin = 16.4 °C, Tmax = 25.9 °C). Showers took place only in the late afternoon after the sampling of the soil samples. The main wind direction was from the west (with 4 m/s wind speed). The weather was sunny and unclouded on 8 September 2016 with temperatures of 21 to 24 °C (Tmin = 14.7 °C, Tmax = 27.8 °C). The main wind direction was from the southeast to east (with 2–3 m/s wind speed). Weather information was retrieved from the ZAMG already for a previous study (Bastl et al. 2017b).

The aerobiological samples were evaluated following the standards of the European Aerobiological Society and the EAN Database (Galán et al. 2014). All aerobiological samples were evaluated to gain daily mean pollen concentrations by the same analyst (MK) to avoid intra-observer error.

Surface soil samples were gathered with gloved hands by grabbing randomly the uppermost soil material from the ground-surface from an area of about half a metre under and around the trap (Figure 1B, D). This way of collecting ensured a representative sample from the area. The surface soil samples included plant debris, pebble stones, dust (both soil samples) or moss (for the rooftop soil sample; Figure 1B) as well as leaves and sometimes twigs (for the ground soil sample; Figure 1D) besides the uppermost organic soil horizon material (O-horizon). It was intended to sample the most recent material like achieved in forensic palynology; however, the age of the soil samples is not known. The samples were thoroughly washed in distilled (pollen-free) water. A drop of Tween 20 was added to the water. The liquid fraction was transferred into test tubes and centrifuged at 3000 rpm for 2 min, in order to settle pollen grains and other residues at the bottom of the test tubes. Acetolysis was carried out with the polleniferous material. Samples were dehydrated with concentrated acetic acid followed by an acetolysation in a mixture of nine parts acetic anhydride and one part concen-

Table IV. Percentage per taxon evaluated (35 pollen taxa/groups in alphabetical order) assessed on the grass day (May 30th 2016) from the four compared samples: outdoor rooftop pollen concentrations, soil sample from the rooftop, outdoor ground level pollen concentrations and soil sample from the ground.

Evaluated taxa 30 May 2016	Rooftop sampler (%)	Soil sample rooftop (%)	Ground sampler (%)	Soil sample ground (%)
<i>Acer</i>	—	1.0	—	0.6
<i>Aesculus</i>	—	0.3	—	0.1
<i>Ailanthus</i>	—	0.3	—	—
<i>Alnus</i>	1.2	2.1	—	0.9
Amaranthaceae	—	—	—	0.1
<i>Ambrosia</i>	—	—	—	—
Apiaceae	—	—	0.2	—
<i>Artemisia</i>	—	0.3	—	—
Asteraceae	—	0.3	—	0.6
<i>Betula</i>	1.2	9.8	0.2	3.9
Brassicaceae	—	1.5	—	—
<i>Carpinus</i>	—	0.8	—	0.3
Caryophyllaceae	—	—	1.1	—
<i>Castanea</i>	—	0.3	—	—
<i>Corylus</i>	—	1.0	—	0.4
Cupressaceae	1.2	4.9	0.9	0.1
Fabaceae	—	—	—	0.4
<i>Fagus</i>	1.2	5.4	0.2	4.4
<i>Fraxinus</i>	—	1.3	—	0.4
<i>Juglans</i>	—	0.3	0.2	0.8
<i>Mercurialis</i>	—	—	—	—
<i>Plantago</i>	14.8	11.1	17.3	7.3
<i>Platanus</i>	—	2.1	—	0.1
Poaceae	55.6	31.0	75.0	75.0
<i>Populus</i>	—	0.5	—	—
<i>Quercus</i>	1.2	3.9	0.2	1.5
Ranunculaceae	—	—	—	1.5
Rosaceae	1.2	2.6	0.2	0.2
<i>Rumex</i>	—	1.0	0.2	—
<i>Salix</i>	—	0.3	0.2	0.1
<i>Sambucus</i>	8.7	10.1	2.1	0.3
<i>Tilia</i>	3.7	0.8	—	0.1
<i>Ulmus</i>	—	—	—	0.1
Urticaceae/Can.	7.4	3.6	1.6	—
INR	2.5	3.1	0.5	0.9

trated sulphuric acid at 80 °C for 10 min (Hesse et al. 2009). Chlorination was not performed. After acetolysis, the samples were rinsed in acetic acid and water. Glycerine was then added to the samples to form a suspension which was then transferred to a glass slide for light microscopic investigation. Pollen grains were identified, counted and assigned to specific plant taxa. All surface soil samples were evaluated by the same analyst (MW) to avoid intra-observer error. Percentages of the respective pollen taxa were computed to allow easier comparison between the two sample types (Tables II–VI).

Statistics

We chose the methodology used in Bastl et al. (2017b) and computed Kendall rank correlation coefficients between the different measurement

points (pollen concentrations and surface soil samples) for comparing the compiled measurements in this study. Kendall rank correlation coefficients are the method of choice when the ordinal association between two measured quantities shall be assessed and was preferred over Spearman rank due to its higher suitability for our dataset (*P*-values are more accurate with a smaller sample size). A rank correlation is robust since it does not use the metric information, but the rank of the values which is required for our datasets; this rank correlation gives a measurement between -1 and 1 on the dependency of two data vectors. A linear dependency between the different methods (air and surface soil samples) was not obvious and not expected due to the difference in methodology (sampling, preparation and analysis). Therefore, Kendall rank correlation coefficients were chosen to assess similarity or dissimilarity of

Table V. Percentage per taxon evaluated (35 pollen taxa/groups in alphabetical order) assessed on the ragweed day (September 8th 2016) from the four compared samples: outdoor rooftop pollen concentrations, soil sample from the rooftop, outdoor ground level pollen concentrations and soil sample from the ground.

Evaluated taxa 8 September 2016	Rooftop sampler (%)	Soil sample rooftop (%)	Ground sampler (%)	Soil sample ground (%)
<i>Acer</i>	—	—	—	0.5
<i>Aesculus</i>	—	0.5	—	—
<i>Ailanthus</i>	—	—	—	—
<i>Alnus</i>	—	2.4	—	1.8
Amaranthaceae	6.2	7.2	7.8	2.3
<i>Ambrosia</i>	67.6	40.2	65.9	2.1
Apiaceae	—	—	—	—
<i>Artemisia</i>	3.5	2.9	2.2	0.3
Asteraceae	0.7	1.9	—	6.7
<i>Betula</i>	—	2.1	—	4.4
Brassicaceae	—	—	—	0.3
<i>Carpinus</i>	—	0.5	—	1.0
Caryophyllaceae	—	0.5	—	0.8
<i>Castanea</i>	—	0.5	—	0.3
<i>Corylus</i>	—	0.8	—	1.0
Cupressaceae	—	0.8	0.6	—
Fabaceae	—	—	—	0.3
<i>Fagus</i>	—	0.3	—	1.3
<i>Fraxinus</i>	—	0.5	—	0.3
<i>Juglans</i>	—	—	—	1.0
<i>Mercurialis</i>	1.4	1.3	1.1	—
<i>Plantago</i>	0.7	7.2	5.6	55.9
<i>Platanus</i>	—	0.3	—	—
Poaceae	8.3	12.5	7.8	14.4
<i>Populus</i>	—	—	—	—
<i>Quercus</i>	—	1.1	0.6	0.8
Ranunculaceae	—	0.3	—	0.3
Rosaceae	—	0.5	—	—
<i>Rumex</i>	0.7	—	—	—
<i>Salix</i>	—	—	—	—
<i>Sambucus</i>	—	—	—	—
<i>Tilia</i>	—	5.9	—	2.1
<i>Ulmus</i>	—	0.3	—	—
Urticaceae/Can.	11.0	7.2	8.4	—
INR	—	1.6	—	2.5

the compared datasets. In addition, a significance test was performed for each computed rank correlation to test the coefficient against zero. We refer to the computed Kendall's tau coefficients just as 'coefficient'. This comparison was conducted on the whole dataset (all four days combined), separately for each day and for groups (season days versus non-season day). R software 3.3.1 was used for this analysis.

Results

The outdoor air (rooftop and ground) samples were assessed by the same method and the surface soil samples (rooftop and ground) were assessed by the

same method resulting in four samples for each day. These two different datasets can be directly compared in Tables II–VI as percentages. Pollen was mostly well preserved and fresh in the air samples. The surface soil samples from the rooftop and the ground level show differences. Pollen grains in the ground level samples are more destroyed than in the rooftop samples.

The winter day (Table II) was characterised by nearly no pollen in the air (rooftop and ground sampler), but a high diversity in the surface soil samples (rooftop and ground) containing nearly all major pollen types contributing to the pollen season and assessed during this study although most of them in a low frequency (Figure 2A, B). The spectrum was dominated by pollen of the Poaceae family and *Tilia*. More pollen taxa were identified in the surface soil sample from the ground than from the rooftop. The only pollen recorded in the air samples was pollen from the Urticaceae in the ground sampler.

The birch day (Table IV) was characterised by more similar frequencies of pollen taxa in the air samples than in the surface soil samples. The air samples were dominated by a high occurrence of *Betula* followed by *Populus*, *Carpinus* and Cupressaceae (all above 10%). The surface soil samples were dominated by *Carpinus* and *Betula* and followed by other pollen types (*Populus* and *Acer* in the rooftop sample and *Alnus* and Cupressaceae in the ground sample). Overall, the air and surface soil samples from the rooftop are more similar to each other than the air and the surface soil samples from the ground. The surface soil samples show higher numbers of *Acer*, *Alnus* and *Carpinus*, similar numbers of *Fraxinus* and lower numbers of *Betula* and Cupressaceae (Figure 2C, D). The seasonal impact of certain pollen types (*Betula* and *Carpinus*) is found in all samples. The highest diversity of pollen taxa was recorded in the surface soil sample from the ground.

Table VI. Statistical results of the Kendall's tau correlation for: each of the four study days separate, the winter day versus the season days and all days together.

Sample days	Rooftop sampler – soil sample rooftop	Ground sampler – soil sample ground	Soil sample rooftop – soil sample ground
Winter day	NA	–0.18	NA
Birch day	0.65*	0.71*	0.83*
Grass day	0.61*	0.23*	0.58*
Ragweed day	0.52*	0.20	0.77*
Winter day	NA	–0.18	NA
Season days	0.50*	0.39*	0.73*
All days	0.39*	0.27*	0.73*

The asterisk (*) highlights significantly positive *p*-values for most of the pollen season days. NA, not available.

The grass day (Table V) was characterised by a clear dominance of Poaceae pollen in all samples, although least in the surface soil sample from the rooftop. The second highest frequency was recorded for *Plantago* (in all samples) and for *Sambucus* (rooftop samples). The air samples showed overall similar results although less than for the birch day. Main differences concerned the higher frequency of Poaceae and *Plantago* pollen in the air sample from the ground versus the higher occurrence of *Sambucus* and Urticaceae pollen in the air sample of the rooftop. The surface soil samples showed an increased diversity in comparison to the air samples. Frequencies are similar for most taxa, but major differences occurred for Poaceae (higher in the surface soil sample from the ground) and for *Plantago*, *Betula*, and *Sambucus* (higher in the surface soil sample from the ground; Figure 2E, F). Overall, the air and surface soil samples from the ground are more similar to each other than the air and surface soil samples from the rooftop (in contrast to the birch day). The seasonal impact of certain pollen types (Poaceae and *Plantago*) is recorded in all samples. The highest diversity of pollen taxa was recorded for the surface soil sample from the rooftop.

The ragweed day (Table VI) was characterised by the high occurrence of *Ambrosia* pollen in three of the four samples and the significantly different findings for the surface soil sample from the ground. The frequency of Urticaceae, Poaceae and Amaranthaceae were the next highest ones in the air samples, whereas this sequence was different in the surface soil sample from the rooftop (Poaceae, Urticaceae, Amaranthaceae). The surface soil sample from the ground differed completely and was dominated by *Plantago* followed by Poaceae, Asteraceae and *Betula* (Figure 2G, H). The results of the air samples are well comparable, similar to those from the birch day. The surface soil samples differed clearly from each other with the surface soil sample from the rooftop showing higher similarity with the air samples concerning the frequencies and higher similarity with the surface soil sample from the ground concerning the diversity. The highest diversity of pollen taxa was recorded for the surface soil sample from the rooftop.

The surface soil samples showed a higher diversity in pollen taxa when compared with the air samples. The highest divergence in air and surface soil samples was observed for the winter day, whereas the most similar results were observed for the birch day. This finding is supported by the computed coefficients. No coefficients could be computed in most instances for the winter day. The birch day showed the highest significance

in terms of similarity followed by the grass and the ragweed day. The three season days showed significant values when compared with the winter day and all days together result again in highly significant overall results. In general, the coefficients were more significant for the rooftop air and the rooftop surface soil sample than for the ground air and the ground surface soil sample. The surface soil samples (rooftop and ground) were significant for all coefficients computed except for those on the winter day.

Discussion

Daily mean pollen concentrations are the fundamental dataset for aerobiology and pollen information services to assess the state of the pollen season and to answer the question of pollen types present/absent in the ambient air. The air samples analysed herein showed a strong impact of the season with a high frequency of the pollen taxon that dominates (birch, grass and ragweed pollen season). In contrast, rather clean air was recorded during winter time, when the flowering time is over/has not yet started. This is contrasted by the results from the surface soil samples. Surface soil behaves more like dust as a pollen archive (Hevly 1981; Preusche & Weber 2014) although pollen preservation or pollen corrosion depends strongly on many factors among them microbial attack, oxidation, mechanical forces, temperature, sporopollenin content, chemical and physical composition of the pollen wall (Haviga 1967), chemical composition and decomposition (Webster et al. 2008) as well as soil faunal activity concerning redistribution of pollen (Davidson et al. 1999). However, pollen will be preserved for some time in soil, whereas it may vanish quickly from the air as soon as flowering activity is finished. Therefore, it was expected to find a higher diversity of pollen taxa in surface soil samples in comparison to the air samples. It is most probable, that sampling did not affect the results, because soil samples were taken randomly and not from the exact same spot.

The surface soil samples from the rooftop and the ground are in general comparable for most days (winter, birch, grass day) as the air samples are for all sample days, although in a cruder extent (e.g. for the winter day). The surface soil samples show mainly a higher diversity of the pollen spectrum when compared to the air samples, probably related to a longer preservation in soil than in air.

However, there are differences within the surface soil samples, as well as differences in surface soil



Figure 2. Pollen spectra of the surface soil samples. All plants with a frequency more than 1% are shown in separate bars, all the others are summarised in the 'INR'-bar. Bars of same taxa have the same colour. **A.** Rooftop sample collected 14 December 2015; 'winter day'. **B.** Ground level sample collected 14 December 2015; 'winter day'. **C.** Rooftop sample collected 4 April 2016; 'birch day'. **D.** Ground level sample collected 4 April 2016; 'birch day'. **E.** Rooftop sample collected 30 May 2016; 'grass day'. **F.** Ground level sample collected 30 May 2016; 'grass day'. **G.** rooftop sample collected 8 September 2016; 'ragweed day'. **H.** Ground level sample collected 8 September 2016; 'ragweed day'.

and air samples from different heights. The surface soil sample from the rooftop and the air samples from the rooftop were more similar on the birch and the ragweed day, whereas the surface soil sample from ground level and the air samples on ground level were more closely related on the grass day. Local aspects can explain this result. Most trees inducing respiratory allergies (e.g. birch, ash, hornbeam) are widely distributed in

Vienna and produce a lot of pollen which is more or less homogeneously distributed in the air (Bastl et al. 2019). Hence, a close relation between the surface soil sample at the rooftop level and rooftop air is to be expected on the birch day. Moreover, the high percentage of *Acer* pollen grains in the rooftop surface soil sample suggests the pollination of local *Acer* trees. Pollen of *Acer* is mostly insect pollinated and withered flowers accumulate on the ground

after the pollination period. Therefore, *Acer* pollen may well accumulate easier in soil samples than in the air samples.

The marked difference on the ragweed day in both surface soil samples compared to air samples is worth discussing. Whereas *Ambrosia* dominated the rooftop surface soil sample, *Plantago* dominated the ground surface soil sample (Figure 2). Also, in this case, local aspects have to be considered: *Ambrosia* did not grow on the ground of the ZAMG (Table I). In addition, pollen concentrations of *Ambrosia* are constituted in Vienna of the local plants in Austria and of the long distance transport from more infested regions in southeast Europe. Therefore, the rooftop surface soil sample recorded a higher frequency of *Ambrosia* and the percentages lay between the air samples and the ground surface soil sample (Table IV). The ground surface soil sample was impacted by the local flora on ground level mainly from the herbaceous plants such as *Plantago* and Poaceae. Both taxa were also dominant during the grass day and resulted in a closer relation of ground surface soil and ground level air measurements. Moreover, episodes of long distance transport of *Betula* could explain the high percentages in the surface soil of the rooftop level on the grass day compared to air samples and ground level surface soil.

Other local aspects included the plant composition of a large tree of *Tilia* in vicinity to the Karl-Kreil building and Cupressaceae. Cupressaceae pollen was found in most of the samples, but occurred later in the surface soil sample from the rooftop. The ground level trap and the spot for ground surface soil sampling are further away than the rooftop spot in a direct line. *Tilia* pollen was found in some or all of the samples on the winter, grass and ragweed days. The dominance of *Tilia* on the winter day may be explained by its local accumulation in the surface soil sample from the rooftop.

The air samples from rooftop and ground level are very well comparable with each other (Table II–IV). However, differences occur and are most pronounced on the grass day. This finding can be explained by the operating height of the devices. The ground sampler operates at 1.6 m height and is surrounded by local vegetation, especially Poaceae and *Plantago*. Therefore, those herbaceous plants show a higher frequency in the ground air sample. Two whole pollen seasons (2015–2016) were compared in Bastl et al. (2019) and show a high significant positive relationship between the data from the rooftop and the ground level trap.

Differences between the surface soil samples have to be considered as well (Figure 2): there is a spatial component apparent, even though both locations were close to each other at the grounds of the ZAMG within the same vegetation, but separated in height from each other. The surface soil sample from the rooftop is dominated by *Tilia* followed by Poaceae and *Ambrosia* pollen, whereas the surface soil sample from the ground is dominated by Poaceae, *Plantago* and *Ambrosia* pollen (with *Tilia* pollen as fourth most frequent pollen type) on the winter day. The birch day shows more similarities between the two surface soil samples, but differences can be noted, e.g. a higher diversity in the ground surface soil sample with higher frequencies of *Salix*, *Ulmus* and *Corylus*. Diversity is higher in the rooftop surface soil sample on the grass day, because the ground surface soil sample is dominated by Poaceae pollen (more than 70%). Differences are very high between the rooftop and the ground surface soil sample on the ragweed day. The frequencies of *Ambrosia* and *Plantago* are nearly vice versa between the two samples. These results suggest that the spatial component has a strong impact on surface soil samples. Hence, two different spots (at different heights), but in close vicinity to each other may show a different composition of the pollen spectra (soil samples from the ground and the rooftop), but may be compared to air samples from the same spot (see earlier).

Most pollen types found were also present as local plant source on the grounds of the ZAMG (Table I). It should be noted, that only *Alnus*, *Ambrosia*, Brassicaceae, *Castanea*, *Mercurialis* and *Rumex* are not present locally. *Ambrosia* occurs more frequent in the surface soil sample from the rooftop (Figure 2). We attribute this to the fact that it does not grow locally. Brassicaceae, *Castanea*, *Mercurialis* occur as well more in the rooftop than in the ground soil sample, but not as significant as *Ambrosia*. *Alnus* follows this pattern on three of the sample days with the exception of the birch day, when it appears more frequent in the ground surface soil sample. *Rumex* shows no clear pattern and is present only in some surface soil samples from the ground or the rooftop.

Pollen preservation and degradation was an interesting topic for the surface soil samples. Pollen grains in the ground level samples are more destroyed than in the rooftop samples. This is to be expected as the rooftop is an exposed aggregate concrete with little surface soil accumulation where the microbial activity is correspondingly lower than in the surface soil at the ground.

The coefficients substantiate the finding that air and surface soil samples from the same site can be

compared and correlate during the pollen season. This might be an interesting aspect for forensic palynology and interdisciplinary research that works with palynology. It is important to take the time of the season when a sample is taken as well as the spot where the sample is gathered into account. Forensic palynology already samples the exact location, if known, and considers also reference samples of other potential spots of interest. Our results emphasise the impact of very local effects, which are a fundament of forensic palynology. We found herein a seasonal aspect, especially for air samples, and a spatial aspect, especially for surface soil samples, which should be considered in future studies and all palynological applications.

Limitations

Limitations of this study comprise mainly the methodology used, among this the limitation of data collection, sampling efficiency and the nature of the samples examined.

The methodology of the surface soil and the air samples differs in various parts including the sampling itself and the evaluation procedure. Thus, the raw data cannot be directly compared. Therefore, Kendall's tau correlation coefficients were chosen to take this into consideration. However, the quantitative aspect cannot be assessed due to the different procedures.

Sampling efficiency and possible errors are well known for Hirst-type pollen traps and standards for aerobiological routines are already employed (e.g. Galán et al. 2014). Surface soil samples are subjected to a range of factors that influence the preservation of pollen such as type of soil as well as faunal activity (Davidson et al. 1999), pollen type and probably climate zone (Phuphumirat et al. 2009). Possible filter effects (faster/slower degradation of particular pollen types) cannot be ruled out.

The samples represent only a snapshot in the pollen season (2 h on four different days) and not the entire pollen season itself. The surface soil analysis allowed an in-depth study, but data collection was limited and the methodology is not applicable as routine application. Hence, we formulate our conclusions with caution although the overall outcome of the study seems to be robust.

Conclusions

To our knowledge, our study is the first to examine seasonal qualitative changes of air and surface soil samples including the most important outdoor aeroallergens. The novelties of this study include (1) a combination of forensic and aerobiological methods

to assess the pollen spectrum, (2) the in-depth study of the whole pollen spectrum including all relevant pollen types for pollen allergy sufferers instead of a single or few pollen types, (3) the qualitative aspect assessed by Hirst-type pollen traps to compare air samples with surface soil samples, and (4) sampling during different pollen seasons (birch, grass and ragweed) as well as during the winter providing a reference outside the pollen season to capture the seasonal signal in both sample types.

Our results showed a highly significant correlation between datasets from air and surface soil samples especially during the pollen season suggesting a seasonal impact. The seasonal impact was higher in the air samples than in the surface soil samples. The strong similarity between both sample types indicated the usefulness of surface soil samples and air samples to characterise a certain locality. Further, pollen concentration data might be of interest (e.g. forensic palynology) to characterise a particular area. A distinction must be made between local taxa that grow in proximity to the sampled area, the height of devices used and taxa that derive mainly from long distant transport (such as *Ambrosia* in this study).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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